A review of batting in men’s cricket

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Accepted 29 November 1999

In this review, we critically evaluate the scientific research into the morphology and physiology of cricket batsmen. We consider all aspects of the motor control of this skill, in the context of research into dynamic interceptive actions, the biomechanics (kinematics and kinetics) of the various phases of batting strokes and injuries to batsmen. Some attention is also devoted to batting equipment and to psychological factors in batting. Because of the lack of published scientific research into women’s cricket, this review focuses on the men’s game and covers research on batsmen of various playing standards. For the future, we see as a high priority research into injury mechanisms, rather than simple injury statistics, and the role of cricket equipment design in injury prevention. A second priority is for multi- or inter-disciplinary research, linking the biomechanics of batting to the underlying motor control of the movements and the effect of environmental information. Biomechanical studies of the variability of the batsman’s movements are needed, and these should be related to the compensatory variability proposal of ecological psychology. Clearly, there is also a need for scientific research into batting in women’s cricket, which has been inadequately researched to date.

Keywords: biomechanics, cricket batting, injury, motor skills, physiology, psychology.

Introduction

Batting in cricket requires motor and psychological skills to play the best shot from a wide repertoire of attacking and defensive strokes against bowlers of different types – fast, spin, seam and swing. A good innings can last several hours (occasionally, days) and will involve the batsmen running the length of the pitch (about 19 m) for each run scored (other than boundaries), wearing protective equipment, including pads and helmet. The fitness and morphology of the batsman are, therefore, also important. Previous reviews of scientific research into cricket have concentrated on the biomechanical and injury aspects of fast bowling (Bartlett et al., 1996; Elliott et al., 1996). The aim of this review is to evaluate the scientific research into the morphology and physiology of batsmen, their motor skill, the biomechanics of batting, injuries, the equipment used and the psychology of the game. Because of the lack of published scientific research into women’s cricket, this review focuses on the men’s game; therefore, we use the traditional term batsman, rather than batter, throughout.

Morphology

Studies of the morphology of cricket batsmen are limited. Most of these have been conducted as part of research on cricketers in general rather than batsmen in particular (Foster and Elliott, 1985; Elliott et al., 1986; Stretch, 1987, 1990; Peens, 1996). A tall, athletic build, with morphological differences between batsmen, bowlers and all-rounders, has been found for international cricketers and for those of provincial, county and state standard. Mean somatotype ratings of 2.5–5.3–2.1 (Stretch, 1987) and 3.1–5.5–2.0 (Stretch, 1990) for provincial and 3.8–4.4–2.4 (Peens, 1996) for club cricketers have been documented. Provincial batsmen (Stretch, 1987: 2.5–5.2–2.0; Stretch, 1990: 3.0–5.7–2.0) and club batsmen (Peens, 1996: 3.7–4.5–2.4) have been found to have endo-mesomorphic somatotypes. It could, of course, be argued that this research shows little more than a bias towards large fast bowlers. Anthropometric differences have been

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found between batsmen and bowlers, with the batsmen tending to be shorter and lighter than the bowlers, but having a greater relative fat mass. Bowlers have been shown to have a significantly greater androgyne index and absolute muscle and bone masses than batsmen (Stretch, 1987, 1990). It may be that bowling selectively favours larger and taller players; for batting, size is not necessarily advantageous.

**Physiological factors**

The importance of physical conditioning to complement a cricketer’s skills has been emphasized by Pyke *et al.* (1975), Foster (1978), Davis (1984) and Tyson (1985), particularly in the constraints of limited-overs matches. This aspect of cricket batting has been badly neglected by sport scientists, as is evident from the lack of reported research. Foster (1978), Briggs (1980), Davis (1984), Tomlin and Popplewell (1991) and Bull *et al.* (1992) have drawn up guidelines for training and for the evaluation of the fitness of cricketers. Much of this work has been based on subjective evaluations, rather than empirical scientific research, with some application of basic physiological principles.

Using a portable calorimeter (Kofranyi Michaelis), Fletcher (1955) determined the mean energy expenditures for college cricketers playing in the nets to be 1004 kJ·m⁻²·h⁻¹ for batting and 1012 kJ·m⁻²·h⁻¹ for bowling. Energy expenditure during match-play was calculated by analysing the time spent in the component activities and multiplying these times by the experimentally determined energy expenditure for each activity in the nets. During inter-college matches, energy expenditures of 765 kJ·m⁻²·h⁻¹ for batting, 665 kJ·m⁻²·h⁻¹ for bowling and 468 kJ·m⁻²·h⁻¹ for fielding were estimated. In an international Test match, it was predicted that the energy expenditures for batsmen, bowlers and fielders were 648, 531 and 368 kJ·m⁻²·h⁻¹, respectively. The American College of Sports Medicine (1990) classified the energy cost of playing cricket in general ± 4.6–7.4 METS.

Foster (1978) monitored the activity patterns and telemetered heart rates of first-class cricketers. He reported that the activity patterns of batting, bowling and fielding showed that players were required to repeat many intensive activities, which do not normally last more than 20 s. Cricketers rarely sprint more than 70–80 m, with a distance of ~20 m the most common: this is roughly the distance covered by each batsman for a ‘run’. The energy for this is supplied by anaerobic sources, using ATP-PC and the lactic acid energy system. The aerobic energy source is used during recovery as well as to replace the phosphate stores in preparation for the next bout of intensive activity. Foster’s contention was that cricketers need to be able to repeat many intensive efforts lasting on average 10–20 s. These brief periods of intense activity need to be repeated, although at different regularities and frequencies, by batsmen, fast bowlers and fielders. An interval-training programme was recommended by Foster (1978) to develop both the aerobic and anaerobic energy systems most effectively.

It could be argued that future research needs to determine more clearly the demands of batting in particular rather than cricket in general (see, for example, Davis *et al.*, 1994). Stretch and Buys (1991) reported no significant differences in speed and agility between batsmen, bowlers, all-rounders and wicket-keepers taking part in the South African Universities Students Cricket Week. Comparisons between those who had played at provincial standard and those who had only played club cricket showed that provincial players tended to perform better in the tests than club players. The running speed (time to run three runs) of the batsmen was faster than for the other groups, although they had the slowest 50 m dash times and were ranked third in the shuttle run test of agility. These contrasting results appear to indicate that the ability to run with pads on – and the skill of running between the wickets (as assessed by the time to run three runs) – play an important role here; batsmen may have refined these skills through batting in matches.

**Motor skills: Perception and action in cricket batting**

Batting in cricket is an example of a dynamic interceptive action, which Whiting (1969) placed in his second, most complex, category of ball skills – that encompassing task constraints where a ball has to be received and sent away in the same movement. Skilful performance of dynamic interceptive actions is fundamental to success in many ball games. To psychologists, they have represented a useful vehicle for developing theoretical understanding of the relationship between perception and action in goal-directed behaviour (e.g. Whiting, 1969; Bootsma, 1988; Williams *et al.*, 1992, 1999; Harris and Jenkin, 1998).

The spatio-temporal constraints of dynamic interceptive actions in ball games

Although there is little specific research on the processes of perception and action during cricket batting, some previous work has been done on similar dynamic interceptive tasks, including striking in fast ball sports such as baseball and table tennis. Because of the similarities
in task constraints across fast ball games involving striking, it may be instructive to compare how top-class players satisfy the severe demands on their perceptual and motor systems. In this section, we review some of the more general work on interceptive actions that is relevant to cricket batting performance.

The key to successful coordination and control of dynamic interceptive actions is for the intercepting limb or implement to be in the right place at the right time (Savelsbergh and Bootsma, 1994; Regan, 1997; Williams et al., 1999). When performing dynamic interceptive actions, athletes need precise information to locate the ball in space (‘where’ information) at a specific time (‘when’ information). Savelsbergh and Bootsma (1994) have argued that three task constraints need to be satisfied for successful performance of dynamic interceptive actions in sport. Performers need to: (i) ensure that they contact a moving projectile in the environment; (ii) contact it with the intended velocity; and (iii) contact it with an intended spatial orientation to satisfy the accuracy requirements of the task. Successful interceptive actions require good coordination not only between relevant parts of the movement system, but also between relevant motor system components and the projectile to be intercepted. The latter is a difficult task, which can be performed with some success by most humans (Bootsma and Van Wieringen, 1990; Regan, 1997).

Quantitative descriptions of projectile speeds in cricket have indicated that the temporal constraints on cricket batsmen are severe. For example, Glencross and Cibich (1977) found that a ball delivered at 40.2 m·s⁻¹ took 439 ms to reach the batsman. It was assumed that the movement time was 250 ms, leaving just 189 ms to react to the ball. The batsman also needs to pick up visual information on late deviations in flight because of added complications, such as spin, swerve or drag effects. These findings are broadly in line with those of Regan (1997), who demonstrated how cricketers often have only 230 ms to deal with late fluctuations in the flight of a ball approaching at 44.4 m·s⁻¹. If one accepts the temporal values from these analyses, it is clear that, to bat successfully, cricketers have to initiate some movements, such as the backswing in the bi-phasic batting action, before delivery of the ball. The temporal constraints of spin bowling are a little better, but for a ball delivered at 18 m·s⁻¹, Regan (1997) calculated that it would hit the ground ~940 ms after release. Visual reaction time was estimated at 150 ms and movement time for the stroke at 200 ms, leaving about 600 ms for perception of flight characteristics. Regan’s (1997) analyses of the temporal constraints of slow bowling proposed an appreciable portion of time for perception of flight characteristics. He argued that this period could be filled with unreliable information, owing to human weaknesses in judging absolute distance and speed, beyond a few metres from the point of observation.

To understand processes of perception and action in dynamic interceptive actions, it is relevant to ask how skilled players pick up visual information to satisfy the spatio-temporal task constraints of batting.

Processes of perception and action: Theoretical approaches

In the study of perception and action during dynamic interceptive actions, there have been at least two distinct avenues for research. One line of work has tended to focus on how dynamic interceptive actions can be instantaneously regulated by perceptual information (e.g. haptic, proprioceptive, auditory and visual) when there is sufficient time available (Solomon and Turvey, 1988; Savelsbergh and Bootsma, 1994). This approach typically emphasizes the role of receptor anticipation processes, in which actions need information for initiation, completion and on-line guidance (Gibson, 1979; Harris and Jenkin, 1998; Williams et al., 1999). Functional on-line adjustments are necessary because early retinal image information on ball flight is unreliable, as the human visual system has difficulty estimating the absolute distance and absolute speed of an approaching object (Regan et al., 1998). This is an apparent limitation that skilled bowlers seek to exploit by such strategies as holding the ball loosely or hyperextending the wrist at delivery to vary bowling speed and flight along the same trajectory (Regan, 1997). Despite this neurally based limitation, the human visual system can instantaneously predict the trajectory of a ball to within less than 0.5° of the visual field and can perceive time-to-contact information to within ±2 or 3 ms (Lee, 1980; Bootsma and Van Wieringen, 1990; Regan et al., 1998). Skilled cricketers learn to cope with these visual system limitations through the development of a continuous link between the perceptual and action systems, which allows them to use receptor anticipation processes late in the stroke to make ongoing adjustments.

Another avenue of research, popular in cognitive psychology, is based upon the notion that the spatio-temporal constraints of fast ball games are often so severe that extensive previous knowledge is required to anticipate perceptually the time-of-arrival of a projectile at a specific point. Traditionally, in cognitive psychology, there has been a tendency to highlight the computational problems involved in performing under the constraints of fast ball sports. In particular, the limited information-processing capacities of the human brain, modelled as a computer, have been emphasized (e.g. Fitts and Posner, 1967; Abernethy and Russell, 1984; Abernethy, 1987). The limitations of the human information-processing system are typically not due
to threshold properties of the performer’s perceptual systems—so-called ‘hardware’ factors (see Williams et al., 1999). Rather, ‘software’ factors have been implicated: extensive knowledge and skill in using the mental processes of perception, attention and memory underpin the inadequacy of the visual system.

The limitations of human information processing were highlighted in early cognitive research on reaction times using static interceptive actions (see also Fischman, 1984; Christina, 1992). For example, mean values of 195 ms were obtained for simple reaction time in an interceptive action in which a statically positioned tennis ball had to be grasped as quickly as possible (Henry and Rogers, 1960). A mean of 36 ms was added to simple reaction times when participants were required to perform an additional task component or the accuracy of movement demands was increased. Given the severe spatio-temporal constraints of fast ball games, these results indicate the importance not only of visual information from ball flight but also of pre-flight information, such as the movements of a bowler (e.g. Williams et al., 1992; Regan et al., 1998). Abernethy and Russell (1984) argued that, because of the restrictive time constraints of fast ball sports at the highest standards of performance, the skilled performer is one who ‘buys’ time for decision-making and response preparation by exploiting advance information from an opponent’s movements. This finding explains why highly skilled games players rarely seem to react to unexpected events, but appear to operate ‘in the future’. They use what has been termed an ‘anticipatory mode’ of action (Whiting et al., 1973).

Skilled cricket batting: An information-processing interpretation

A classical information-processing approach to cricket batting emphasizes that stimulus information from the preparatory movements of a bowler before delivery may be encoded, together with features of early ball flight. When batsmen take up a stance at the crease, they seek any postural cues from the bowler that may assist in perceptually anticipating the line, length and speed of the delivery. Once the ball has been released, parts of the trajectory may be visually tracked and relevant characteristics—such as speed, swerve and spin—have to be identified to predict when and where the ball will pitch. In an inferential process, cues from the event are compared to an internalized representation of the ‘target’ action already stored in memory from many similar experiences (see, for example, Marteniuk, 1976; Barber, 1988). Based on the available perceptual information, a decision is reached about whether there was a match with similar items in memory.

An information-processing approach to interceptive actions, therefore, highlights the role of expert perception in decision-making, planning and stroke execution (e.g. Whiting, 1969; Abernethy, 1987). Expertise in knowing where and when to look for advance information is believed to support perceptual anticipation processes during time-constrained interceptive actions, such as cricket batting (Abernethy, 1981; Abernethy and Russell, 1984). The conclusion that skilled cricketers are more able to infer ball flight characteristics from advance information from the bowler’s body movements has been supported by evidence on foot movement times during batting. For example, data on the foot movements of skilled cricketers batting against fast bowling concur with those of Hubbard and Seng (1954) on step durations of baseball batters. Foot movements were completed before the point of ball–bat contact (Abernethy, 1982).

The propositions of the information-processing approach have rarely been tested in the context of cricket batting. One issue concerns the relevance of the results from studies of reaction time in the laboratories of experimental psychologists to the time constraints of natural performance contexts, such as cricket batting. When the ball deviates, either forward or laterally, during the latter part of flight, the batsman is forced to modify the originally selected stroke under severe time constraints. Are skilled cricketers burdened with reaction times of around 200 ms in response to sudden unanticipated changes in ball flight during cricket batting? McLeod (1987), using a ball projection machine, found that three international class batsmen were not able to make any adjustments to their stroke during the last 180–200 ms of flight. Although he raised the issue of the large moment of inertia of the bat, McLeod (1987) concluded that a range of values around 200 ms should be accepted as the minimum time required for visual feedback to influence initiation of an interceptive action.

Abernethy and Russell (1984) used a film-based reaction time paradigm to examine differences between skilled and unskilled cricketers in batting performance. The task for the groups was to view filmed sequences of the run-up and delivery of two medium-pace bowlers and to verbally report a stroke to play. The skilled group required 22 ms less viewing time than the unskilled group to report a response decision. The results were taken to infer that skilled players use perceptual anticipation strategies to satisfy the severe spatio-temporal constraints of batting against fast bowling. Evidence of the role of visual search strategies in providing advance information is a common feature of research on expertise in sports, including those involving dynamic interceptive actions (Williams et al., 1999). In cricket, Barras (1990) found that skilled batsmen tended to focus on the bowling hand and ball until the bowler was in a side-on position in the delivery stride. Thereafter,
the batsman fixated the anticipated area of ball release above and lateral to the shoulder of the bowling arm. A time lag of 0.94 s occurred between the initiation of the visual fixation of the release zone and the hand appearing. Barras (1990) argued that this temporal delay ensured that the eyes were stationary when the hand appeared to allow the pick-up of visual information.

Although sport scientists have become increasingly aware of the role of advance perceptual information for performance of interceptive actions, bowlers in cricket have also learned about its significance before delivery of a ball. For example, bowlers have developed techniques to either obscure or confuse the relevant visual information from the movement system before delivery. Such techniques include: (1) delaying the onset of critical information, for example by screening the position of the bowling hand with the non-bowling hand or other parts of the body during the run-up; (2) presenting false signals; (3) increasing the amount of information by adopting unorthodox positions before ball release; and (4) constantly varying the parameters of ball delivery and flight, including angle of release, speed, swing, flight and direction. The batsman’s task is made more difficult when a bowler is able to extract late swing in the air or to get the ball to deviate off the pitch. This strategy, as noted by Regan (1997), forces the batsman to rely on information from early segments of ball flight, which the visual system cannot reliably pick up. What can batsmen do in practice to counter these strategies? The capacity to pick up relevant information from the run-up and delivery stride increases the possibility of movement initiation before ball release. Practice should generally involve developing perceptual skill in picking up advance information from the relevant body parts of bowlers. More specifically, videotapes of an opponent’s bowlers may be studied to reveal idiosyncrasies in the run-up and delivery stride, which signal intent.

Response programming

When information about bowlers’ movements and ball flight has been encoded, transformed and perceived, a motor response can be selected from the skilled cricketer’s repertoire to intercept the ball (see Tyldesley and Whiting, 1975). Hubbard and Seng (1954) observed remarkable consistency in the swing times of professional baseball players. The implication is that expert batsmen were able to coordinate the many degrees of freedom of the motor system (i.e. the different parts of the skeletonmuscular apparatus that are free to vary at any instant), by pre-programming the motor response (see Bernstein, 1967). That is, each individual component of the movement system does not have to be controlled separately by the brain. This strategy, based on years of repetitive drills and systematic practice, suggests how skilled cricketers can reproduce a consistent and highly reliable stroke under severe time pressure.

Support for this view emerges from the work of Tyldesley and Whiting (1975), who proposed the concept of ‘operational timing’ as a means by which expert games players reduce temporal uncertainty of an interceptive action by practising until it has a highly consistent duration. They argued that the development of good response consistency through practice signifies that expert performance of dynamic interceptive actions only demands attention to the input and decision-making components of performance. For expert games players, it appears that movement patterns can become so replicable that the spatio-temporal constraints on playing the shot can be reduced to simply one of timing the initiation of movement. In their study of striking actions, at the key points of movement initiation and bat–ball contact, the between-trials displacement differences in the trajectory of the bat for experts were negligible. From this information-processing perspective, trial-to-trial variability was regarded as dysfunctional and due to ‘noise’ in the central nervous system or perturbations within the environment. Other data on response accuracy in cricketers also suggest that skilled players are more accurate in reporting shot selection, particularly during good-length deliveries (Abernethy and Russell, 1984). Taken together, these findings can be taken to support the notion of the development and use of a general motor program for batting strokes by skilled players.

In summary, the findings reviewed in this section illustrate the importance of cricketers developing perceptual anticipation strategies to overcome information-processing limitations when batting. These findings have been criticized for being too specific to experimental contexts in which participants are required to react suddenly to the appearance of visual signals. A clear distinction should be made between these specific constraints and typical performance conditions in ball games, where athletes can modulate ongoing actions on the basis of continuously available information (Bootsma and Van Wieringen, 1990; Whiting, 1991). The methodological techniques used by information-processing theorists have been criticized for other reasons (for a full summary, see Williams et al., 1992, 1999), including problems with ecological validity of the experimental context, an apparent obsession with reaction-time paradigms, the failure to implement realistic movement response measures, and the use of static and small-scale stimulus displays to present information in experiments. We now highlight some of these key criticisms.
Criticisms of information-processing research on timing of dynamic interceptive actions

Traditionally, there has been a tendency to focus on coincidence anticipation or motion prediction tasks in which participants typically have to report verbally when a (suddenly occluded) object or image arrives at a designated target (e.g. Abernethy and Russell, 1984). These paradigms emphasize perceptual anticipation processes, whereas in the study of natural interceptive actions the emphasis is on receptor anticipation processes (Poulton, 1957; Williams et al., 1992; Tresilian, 1995). In dynamic interceptive actions, participants are typically able to view a ball until it is adjacent with the bat. There is ample opportunity for information to provide a steering or guiding role for action. The implication is that the typically distinct constraints of motion prediction and natural interceptive tasks may involve different control mechanisms. In natural interceptive actions, the execution times are far shorter than in motion prediction tasks. Also, the ball is typically able to be viewed for the whole flight (e.g. 300 ms for one-handed catching at 10 m·s⁻¹; Alderson et al., 1974). As evidenced by results on timing from ‘ordinary people’ and infants, the large variability in estimation of time-to-contact typically reported in simulation studies is often not present in the performance of natural tasks such as rapid interceptive actions (Williams et al., 1999). Tresilian (1995, p. 237) also highlighted that ‘the variability (standard deviation of response times) of responses in CA [coincidence anticipation] tasks is some five or six times greater than that observed in IAs [interceptive actions] performed under the same stimulus conditions’. This finding, particularly with the practised observers and skilled catchers, calls into question the use of coincidence anticipation methods, such as film-based tasks, for investigating the timing of dynamic interceptive actions. The use of these unrealistic paradigms to assess dynamic interceptive actions in sport also prevents expert performers from demonstrating a tight coupling between the perceptual and action systems. As we shall see next, ecological psychologists propose this idea as the conceptual basis of the relationship between perception and action.

Perception and action in dynamic interceptive actions: The ecological perspective

In contrast to information-processing accounts, the ecological approach to perception and action emphasizes the high quality of information continuously available for direct perception in the environment (Gibson, 1979). For this reason, information does not have to be embellished by inference with internalized models of the world. The notion in cognitive psychology, that invariant information about actions and objects can be processed and committed to a unified representation of an event in memory, is rejected. This fallacy has been termed the ‘Grand Illusion’ (Harris and Jenkin, 1998). Ecological psychology instead emphasizes the biological constraints on brain functions such as perception and action (Davids and Bennett, 1998). A functional relationship between human perceptual and action systems has evolved to support the behaviours involved in negotiating surfaces and interacting with objects in typical environments (Gibson, 1979). Fundamental behaviours, such as interceptive actions, are exemplified in many ball games. Here, we focus on the visual system as the vehicle for our discussion of key ideas on the ecological approach to perception and action during interceptive actions.

Information a®ords actions. The first key idea of the ecological approach is that ambient light arriving at the eye provides optical information for the performer because it already contains enormous structure. According to Gibson (1979), light reaches the eye after having been reflected off surfaces and objects, such as an approaching cricket ball, in the environment. Light is reflected in straight lines and exists in a highly structured distribution called an ‘array’. In ecological psychology, optic variables refer to the properties of the light reflected in a lawfully structured way from important objects. These properties are available to be perceived directly by all organisms equipped with a visual system. Optic variables come in many forms. They include information on the direction of motion of an object, the distance from an observer that an object will pass, and even the time until it contacts the point of observation (tau) (for detailed reviews, see Gibson, 1979; Lee, 1980; Todd, 1981; Bootsma and Peper, 1992; Michaels and Oudejans, 1992; Williams et al., 1999). Optic variables are characterized by the action possibilities or affordances they offer the sport performer. For example, advance information from body orientation and relative motion of joints in the movement system of a bowler running up to deliver a ball provides affordances for a batsman. As a result of learning, the affordances from the bowler’s run-up and delivery, as well as ball flight, can be exploited by skilled cricketers as reliable sources of information to constrain batting actions. With practice, the actions of a batsman can become tightly geared to the most important informational constraints in specific task conditions.

The evolutionary basis of interceptive timing. A second important aspect of the ecological view is that information is unambiguous and can be perceived directly by the sport performer. This position contrasts strongly with indirect accounts of ‘cues’ as tentative stimuli to be
embellished by internalized representations. From an evolutionary perspective, the textured elements of the environment perturb the flow of light rays in meaningful ways for humans. The continuous availability of information for pick up by purpose-designed perceptual systems is an important element of ecological explanations of the performance of dynamic interceptive actions. It implies an existing sensitivity to the pick-up of optical information from objects during relative approach. The practice and experience of actions in specific performance contexts merely attune existing sensitivity to optical sources of information, which constrain action (Michaels and Beek, 1995).

What evidence is there, in studies of dynamic interceptive actions, for the notion of an evolutionary based sensitivity to optical information from approaching objects? Von Hofsten (1983) videotaped infants aged 34 and 36 weeks reaching towards a brightly coloured object travelling in a circular path in a horizontal plane at speeds of 0.3, 0.45 and 0.6 m·s⁻¹. In total, 144 reaches were analysed to show highly functional accuracy and precision of timing. Only 17 of the trials resulted in the target being completely missed by the infants. In the slowest target speed condition, the mean timing error was only 9.4 ms in an average reaching time of 550 ms. For targets moving at 0.45 m·s⁻¹, with a faster average reach time of 479 ms, the systematic error fell to a mean of 4.4 ms. It is difficult to conceive of infants being able to develop a representation to support such accurate performance of interceptive actions.

Rather, these findings emphasize the view that perceptual processes are supported by smart (i.e. purpose-designed) mechanisms, which have evolved in the human central nervous system to become attuned to specific optical variables (Runeson, 1977). The idea of 'smart visual perception' can be viewed as the 'selective, task-oriented, gathering of information from the visual world' for movement execution (Ballard et al., 1998, p. 93). The role of smart mechanisms in dynamic interceptive tasks is supported by other data showing that precise timing is not just a function of the relatively slow speeds used by von Hofsten (1983) with infants. McLeod et al. (1986) asked non-games players to strike vertically dropping squash balls with paddle bats towards a designated target area. A high consistency was soon reached by the participants in this novel interceptive action, with standard deviations of 10 ms found in 90% of trials and 5 ms in 50% of trials. McLeod and Jenkins (1991, p. 286) have argued that these results suggest that 'ordinary people, without any particular practice' can produce fine timing in dynamic interceptive actions. From these results, it is easy to interpret how expert cricketers can satisfy the task constraints of batting. Observations of expert cricketers playing difficult shots, such as the hook or leg glance, fit these arguments (McLeod, 1987; Regan, 1997). Typically, the most straightforward shot to play is hitting the ball straight down the line. As the game context changes, batsmen might need to play more risky shots across the line of flight of the ball, such as the glance, cut or hook. In the leg glance, for example, the margin of error (estimated by the standard deviation around the mean time taken to perform the action) is minimal. The frontal plane of the blade of the cricket bat (±10 cm wide) is turned almost 90° to deflect the ball past the wicket keeper. Yet skilled cricketers were able to satisfy successfully these severe spatio-temporal constraints against fast bowling at speeds of around 40 m·s⁻¹. In the hook shot, the margin of error in perceiving time to contact information has been estimated at 2.5 ms (Regan, 1997).

For Lee and Young (1985, p. 2), the extraordinary demonstration of timing precision in non-games players and human infants 'suggests that visual-motor systems have evolved which are particularly efficient at detecting time to contact and gearing actions to the information'. Recent modelling and evidence on neural mechanisms in the visual system also provide some support for the evolutionary basis of smart mechanisms in interceptive timing. Regan (1997) and Regan et al. (1998) have modelled how the detection of looming objects during visually guided actions is supported by the presence of specific neural filters in the central nervous system. One crucial retinal detector is the 'motion-in-depth' filter, whose magnitude of output is 'inversely proportional to time to collision' with an approaching object, such as a cricket ball (Regan et al., 1998, p. 186). Wang and Frost (1992) have also reported that specific neurones in the brain respond with heightened electrical activity at a constant time before contact during perception of information from looming objects. The maximum response of the neuronal cells always occurred at a constant time to contact, regardless of changes in size and speed of the approaching stimuli. Motion of the stimuli in other directions, apart from straight towards the point of observation, failed to produce a significant increase in the rate of firing of neurons. Other research has also implicated special-purpose functional divisions in the visual cortex with an evolutionary basis for supporting certain acts (e.g. Harris and Jenkin, 1998; Milner, 1998). This suggests that multiple visual systems may exist in the cortex for extracting different types of information when performing different tasks. One such cortical pathway is dedicated to subconsciously picking up and using visual information for the purpose of controlling actions. The implication is that people may be able to exploit a sensitivity to optical information within the central nervous system when they need to time their actions to rapidly moving objects in space (Harris and Jenkin, 1998).
The studies reviewed above imply that skill in dynamic interceptive actions may be based on an evolutionary sensitivity to optic variables. It would appear that this sensitivity is a resource that can be fine-tuned with context-specific practice in ball games such as cricket (Williams et al., 1999). Skilled cricketers can satisfy the severe task constraints of batting because unambiguous optical information sources are continuously available to be sub-consciously picked up by dedicated visual systems to constrain the assembly of successful interceptive actions. From the emerging evidence, therefore, it is apparent that the earlier account from indirect perception, claiming that cricket batsmen need to somehow encode and transform information before selecting a pre-programmed response, is overly complex. Rather, the process of perception–action coupling is advocated in ecological psychology as the basis of skilled interceptive timing behaviour (Savelsbergh and Bootsma, 1994; Williams et al., 1999).

Acting is not reacting (Whiting, 1991). The notion of perception–action coupling questions traditional assumptions that the performance of skilled batsmen in cricket is limited by simple reaction times of around 200 ms, as discussed earlier (McLeod, 1987). Bootsma and Van Wieringen (1990) criticized previous research postulating visual–motor delays of around 200 ms as artificial. They drew a crucial distinction between the role of visual information to initiate a movement, typically required in laboratory reaction time studies, and its regulatory role in adapting, steering and guiding ongoing ‘real-world’ movements, such as cricket batting (see also Carlton, 1981). Their findings on dynamic interceptive actions in expert table-tennis players, revealed visual–motor delays of 105–122 ms when modifying a forehand drive. Another study of interceptive actions by Lee et al. (1983) found evidence of visual–motor delays of 55–130 ms. The implication is that periods of around 200 ms for visual information processing cannot be justified outside the laboratory, particularly during natural actions when visual information was used primarily to adapt and modify ongoing movement. Moreover, these results are in line with revised estimates from newer, more biological approaches to the study of cognitive processes, which are less ‘black-box-oriented’ than their predecessors.

For example, temporal constraints on the pick-up and comparison of perceptual information with ‘cortical memories’ have been modelled around 80–100 ms, based on what neuroscientists now know about firing times for neurons and local cortical circuitry in the brain (e.g. Ballard et al., 1998).

A functional role for variability. A third proposal in ecological psychology is that of compensatory variability, exemplified in the study of dynamic interceptive actions by Bootsma and Van Wieringen (1990). The ability of experts to modulate precisely ongoing dynamic interceptive actions is predicated on a functional role for movement variability during interceptive actions. Compensatory variability is a functional type of variability. It is an important means by which skilled performers in dynamic environments can produce a tight fit between the current state of the action system and the task goal at the all-important endpoint of execution, through modulating movements on the basis of ongoing perceptual information. They suggested that action systems and perceptual systems could be used to compensate for sudden changes through the covariation of movement duration and initiation time for an interceptive action. Such variability between trials should be viewed as compensatory, because early movement initiations would be locked to slower drives and later ones to faster drives. When the interceptive action was broken up into first and second parts, the higher negative correlations for the first part with mean speed suggested that adaptations were taking place from trial to trial. Evidence for intra-trial variability was also provided in two participants in their study. Smaller movement variability (estimated by the coefficient of variation) was found during the middle to late components of their interceptive actions, not the earliest parts, suggesting that these ‘subjects were still altering their movement during execution’ (Bootsma and Van Wieringen, 1990, p. 27). The visual–motor delays of 105–122 ms observed in four participants suggested that they were still able to pick up movement-regulatory information at a relatively late stage of performance.

These findings provided a theoretical explanation for the data of Hubbard and Seng (1954) on the ability of expert baseball batsmen to covary movement initiation time in relation to ball speed. Furthermore, the results contradicted traditional information-processing assumptions that expert batsmen rely on the known duration of an interceptive action as the basis for timing (e.g. Tyldesley and Whiting, 1975; Abernethy, 1981). Rather, it is apparent that an ongoing process of perception–action coupling allows experts to update interceptive actions continuously, with concurrent perceptual information, until a very late stage of performance. These explanations call into question previous interpretations of how skilled cricketers satisfy the time constraints of batting against fast bowlers (e.g. Glencross and Cibich, 1977; Abernethy, 1981; Abernethy and Russell, 1984). The shorter estimates of visual–motor delay suggest that ongoing adaptations may be feasible at a much later stage of performance than previously believed.

It is clear that, because of its theoretical emphasis on coupling of perception and action systems in dynamic
interceptive actions, the ecological framework has tended to emphasize kinematic measures, using biomechanical techniques of analysis. This approach lends itself naturally to a close relationship between the sub-disciplines of biomechanics and motor control in experimental design. In the next section, we examine the findings of biomechanical studies of cricket batting.

Biomechanics of batting

Several biomechanical studies have been conducted on the swing of a cricket ball and the technique of fast bowling; these are well documented in a review by Bartlett et al. (1996). In contrast, only Davis (1983), Baker (1992), Elliott et al. (1993), Stretch (1993c) and Stretch et al. (1995, 1998a) have illustrated biomechanical principles related to cricket batting and evaluated the effectiveness of coaching points. The research to date on the biomechanics of batting has been essentially descriptive. For example, no research has yet evaluated how coaching style influences the kinematics of batting. The principle of distal-to-proximal sequencing has not been clearly addressed for cricket batting. Perhaps most importantly, the role of compensatory variability (see previous section) in the skill of striking a moving cricket ball with a moving cricket bat has not received attention from biomechanists. Having identified the kinematic and kinetic principles involved in batting, as in the research reviewed below, coaches should be aware of individual differences in the techniques, as skills can be performed in a variety of ways. These limitations should be borne in mind when reading the following sub-sections, in which we have sought to relate the mostly descriptive research findings to biomechanical principles or to views on batting technique in the coaching literature.

The kinematics of batting

Davis (1983) provided insight into the technique of batting and questioned some of the established principles of coaching cricket skills; however, these results were not obtained under well-controlled experiments. For a group of 14 first-class batsmen (two of whom went on to play Test cricket), Stretch (1993c) and Stretch et al. (1998a) compared the kinematics of the front foot drive (D) to those of the forward defensive stroke (FD), which forms the basis of the drive (Greig, 1974; Reddick, 1979; Tyson, 1985; MCC, 1987; Khan, 1989). Their findings confirmed several descriptions in the coaching literature (Greig, 1974; Reddick, 1979; Tyson, 1985; Andrew, 1987; MCC, 1987; Khan, 1989) and highlighted differences between the two stroke patterns.
machines for the learning of techniques and against bowlers for the development of stroke timing and modifications.

The stride and downswing to impact. The differences reported by Stretch et al. (1998a), between the kinematics of the stride and downswing of the bat for the two strokes, are as expected for successful execution of the two strokes and are generally supportive of the coaching literature. Both the instant at which batsmen began playing the drive and the start of the stride occurred later than for the forward defensive; the front foot movement occurred 0.58 s pre-impact (FD = 0.64 s) and the downswing of the bat started 0.36 s pre-impact (FD = 0.38 s). Delaying the forward movement of the foot and the downswing of the bat, when playing the attacking stroke, allows the batsman to assimilate additional ball flight information and, therefore, make final decisions about the execution of the stroke from this temporal and spatial information. This is supported by Glencross and Cibich (1977), Abernethy (1981, 1982), Abernethy and Russell (1984) and Gibson and Adams (1989), who suggested that, only after the batsman has made his initial general response, such as playing forward, can he make the final adjustment to the stroke.

The front foot strides for the two strokes showed no statistically significant differences. This lack of statistical significance, and the limited number of batsmen in the study, hinders the generality of the findings of Stretch et al. (1998a). Nevertheless, the results do allow some quantification of batting technique and the drawing of tentative comparisons with opinions in the coaching literature and with biomechanical principles. Although not statistically significant, the stride for the drive was shorter than the forward defensive (D = 0.68 m; FD = 0.72 m), the front foot was raised higher (D = 0.09 m; FD = 0.08 m) and the stride began 0.06 s later, with the front foot placement occurring later (D = 0.06 s pre-impact; FD = 0.14 s pre-impact). The longer front foot movement time for the drive benefited the summation of forces in the direction of the stroke, leading to a greater impact speed of the bat on the ball, unlike the forward defensive, where the batsman was in a stationary position well before bat–ball impact.

At the instant when the front foot was lifted off the ground in moving forwards to play the drive, Stretch et al. (1998a) reported that the front knee was flexed slightly to 173° (FD = 175°). The front knee angle then reduced to 152° (FD = 159°) at front foot placement, 147° at impact (FD = 156°) and 150° during the follow-through (FD = 149°). This front knee flexion helped the weight of the body to move forward, as suggested in the coaching literature (e.g. MCC, 1987). This weight transfer was further enhanced by raising the heel of the back foot off the ground, also as recommended in the coaching literature (MCC, 1987). The horizontal forward displacement, measured from the front of the boot (D = 0.10 m; FD = 0.05 m), of the toe of the back foot at the instant of contact differed from the recommendations of the MCC (1987). Whereas the MCC recommended that the toe should not drag forwards, moving the back foot forwards may, in fact, help to transfer weight into the stroke.

During the stride phase of the drive, no statistically significant differences were noted between the strokes for the forward (D = 0.35 m; FD = 0.31 m) or downward (D = 0.12 m; FD = 0.09 m) displacement of the head (Stretch et al., 1998a). During the last 0.06 s before impact in the drive, the head moved 0.09 m downwards, ensuring that the batsman’s weight did not shift away from the point of bat–ball contact, which could have resulted in the ball being hit upwards (Tyson, 1985).

The downswing of the bat to execute the drive began with the movement of the hands, forearm and upper arm; this was followed by the movement of the bat forwards and downwards (Stretch et al., 1998a). The front upper arm then accelerated to reach a peak horizontal velocity 0.22 s before impact; the forearm accelerated until 0.20 s before impact, with the back upper arm, forearm and the centre of mass of the bat accelerating into the stroke. The bat reached a peak horizontal velocity (11.8 ± 4.61 m·s⁻¹) at impact, after which all segments decelerated. During the downswing of the drive, the elbow flexed to 113° at the instant the front foot was raised, after which it extended to 129° at impact (Stretch et al., 1998a). This flexion is in line with the coaching view that the downswing of the bat should be carried out with the front elbow flexed and with the bat moving down in a straight line, as close to the body as possible (Tyson, 1985). In cricket batting, the extension of the front elbow might result in ‘its [the bat’s] arc flattening’ (Tyson, 1985), leading to an increase in the radius of the arm and bat segment, which would then increase the tangential velocity of the distal end of the segment (Hay and Reid, 1988), resulting in an increase in the speed of the bat and, therefore, the post-impact ball speed.

Impact. The aim of the drive is to hit the ball with sufficient force to score runs, while still maintaining control of the ball (Stretch et al., 1998a). The success of the stroke can be ascertained from the resultant end-point linear speeds and the interaction between bat and ball. Stretch et al. (1998a) reported that, in the drive, which requires the ball to be hit with both power and accuracy, the difference between the horizontal velocity vectors of the bat (11.8 m·s⁻¹) and ball (20.5 m·s⁻¹) at impact (32.3 ± 5.06 m·s⁻¹) was significantly greater (P < 0.05) than for the forward defensive
(24.2 ± 4.65 m·s⁻¹). This variability is in part attributable to different ball release speeds, even though the same bowler was used. The bat-ball impact speed for the study of Stretch et al. (1998a) is slightly lower than the values reported by Elliott et al. (1993) for the off-(36.4 m·s⁻¹) and on-drives (38.6 m·s⁻¹). The reasons for these discrepancies are not clear; however, it should be noted that both of the values from Elliott et al. (1993) lie within one standard deviation from the mean reported by Stretch et al. (1998a).

The bat-ball impact was 0.20 ± 0.13 m behind the front ankle for the drive (FD = 0.09 ± 0.17 m) and 0.04 ± 0.36 m (FD = 0.11 ± 0.25 m) behind the line of the head (Stretch et al., 1998a). These findings conflict in part with both the coaching literature (Greig, 1974; Reddick, 1979; Tyson, 1985; Andrew, 1987; MCC, 1987; Khan, 1989) and the findings of Elliott et al. (1993); the ball was not played close to the front foot but, at impact, the line of the head was over the ball. At impact, the angular displacement of the bat at 77.8 ± 7.1° to the ground in the drive differed significantly from that of the forward defensive (62.6 ± 6.5°). These results of Stretch et al. (1998a) for the drive support the coaching literature, which recommends that bat-ball impact should occur ‘just before the bat reaches the perpendicular’ (Khan, 1989, p. 21), with the top of the bat ahead of its toe at impact (Tyson, 1985). This should enhance both ball speed, by maximizing the bat speed at impact, and control – the impact in this position would not tend to raise the ball into the air.

The bat reached its peak horizontal velocity in the drive (11.8 ± 4.61 m·s⁻¹) 0.02 s before impact (Stretch et al., 1998a). This is in line with the results of research in golf (Shibayama and Ebashi, 1983), softball (Messier and Owen, 1984) and baseball (McIntyre and Pfautsch, 1982). Stretch et al. (1998a) agreed with the suggestion that the body segments slow down just before contact to prepare for the force of impact.

In the drive, the forward step of the front foot – and the sequence in which the segments reached their peak linear speeds – resulted in a peak horizontal velocity for the bat 0.02 s pre-impact that produced much of the post-impact ball speed (Stretch et al., 1998a). The flexion of the front knee in the drive lowered the centre of mass. This increased the stability of the body (Hay and Reid, 1988), so that the stroke could be played powerfully while still maintaining a correctly balanced position. The back knee flexed slightly to an angle of 145° when playing the drive. During the downswing of the bat, the back foot moved forwards 0.10 m (FD = 0.05 m) to ensure the forward movement of the body’s centre of mass; this accords with the principle of summation of forces in the direction of the stroke (Stretch et al., 1998a).

The pendulum movements of the front upper limb, rotating at the shoulder, elbow and wrist joints, resulted in the sequential peaking of the linear speeds of the segment end-points (Stretch et al., 1998a). These results agree with research in tennis and baseball, in which greater racket and bat impact speeds were found from the striking limb moving as a multi-segmental set of levers (Breen, 1967; Milburn, 1982; Shibayama and Ebashi, 1983; Tyson, 1985; Hay and Reid, 1988; Elliott et al., 1989). In addition, the back elbow reached its peak linear speed at impact, supporting the coaching literature, which suggests that the bottom hand gives power to the stroke (MCC, 1987). The front elbow moved forwards and upwards in anticipation of the movement of the ball after bouncing on the pitch, thereby ensuring that the ball was played into the ground (Stretch et al., 1998a).

Follow-through. The follow-through for the drive is essential for the bat to reach optimal speed at impact. In the study of Stretch (1993c), all batsmen followed-through as suggested in the coaching literature (e.g. MCC, 1987). The post-impact bat horizontal velocity for the drive (11.3 ± 4.21 m·s⁻¹) was significantly greater than that for the forward defensive stroke (2.73 ± 2.88 m·s⁻¹) where there is less of a follow-through, as it is a defensive stroke. During the follow-through of the drive, the bat retains 95% of its pre-impact speed and requires time and distance to allow the body segments to decelerate without interfering with the application of force to the ball.

Kinetics of batting

Stretch (1993a) and Stretch et al. (1995, 1998a) studied the grip forces of the top and bottom hand while batting on a turf pitch against a medium-fast bowler. Their main findings supported the coaching literature, which suggests that the top hand is the dominant hand in the drive and is reinforced by the bottom hand at impact (Greig, 1974; Reddick, 1979; Tyson, 1985; Andrew, 1987; MCC, 1987; Khan, 1989). Similar grip force patterns for the drive and forward defensive strokes were recorded throughout the initial part of the stroke, with greater forces applied by the top and bottom hands just before impact in the drive.

Significant differences were found in the intra-individual means of the top and bottom grip forces when playing the two strokes, as well as for the intra-individual means of the top hand (range = 87.5–138 N) and the bottom hand (range = 32.8–103 N) when playing the drive. This variability may relate both to slight variations in the pace, line and length of the delivery and to differences between players’ styles. The initial grip pressure pattern for the drive was very similar to that of the forward defensive, as the batsman is only...
able to make his final stroke selection based on ball flight information (Abernethy and Russell, 1984; Gibson and Adams, 1989). Fairly constant differences were found between the grip force patterns of the top and bottom hands throughout the early part of the drive. Differences occurred at 0.10 s pre-impact as the top hand applied more force than the bottom hand during the drive.

During the drive, the grip force of the top hand increased, with peak forces of 199 ± 41 N being reached 0.02 s before impact, reducing to 158 ± 56 N at impact and 126 ± 29 N at 0.02 s after impact. A similar pattern occurred in the forward defensive stroke (Stretch et al., 1998a). The pattern is similar to that reported for the speed of the body segments in golf (Shibayama and Ebashi, 1983), softball (Messier and Owen, 1984) and baseball batting (McIntyre and Pfautsch, 1982). The upper limb segments reached their peak linear speeds before impact and were decelerating at impact.

The relaxation of the grip continued until 0.06 s post-impact and was followed by a slight increase in grip force as the necessary hand forces were generated to regain control of the bat after impact and to control the inertia of the bat (Stretch et al., 1998a). A more gradual relaxing of the grip force followed, as the bat was swung through to finish high in front of the batsman. However, the top hand plays the dominant role in the stroke and needs to grip the bat firmly to control the stroke (Greig, 1974; Reddick, 1979; Andrew, 1987; MCC, 1987).

The grip force patterns for the bottom hand during the drive were similar to the top hand, except the forces were smaller, with a peak force of 91.8 ± 41.1 N reached 0.02 s pre-impact, reducing to 86.2 ± 58.2 N at impact and 82.4 ± 28.6 N at 0.02 s post-impact (Stretch et al., 1998a). A rapid relaxation of the bottom hand occurred up to 0.05 s post-impact, followed by a slight increase as the necessary hand forces were generated to regain control of the bat after impact. This was then followed by a more gradual relaxing of the grip force as the bat was swung through to finish high in front of the head.

Centripetal forces up to 320 N have been reported when a golf club is swung, effectively increasing the weight of the golf club about 160 times (Daish, 1972). Similarly, the centripetal forces built up during the downswing and the follow-through phases of the drive in cricket batting may be quite large. Thus, although a particularly strong grip is not likely to add power to the shot, an effective grip is necessary to sustain the centripetal forces generated in the execution of the attacking strokes in cricket. Such a grip may lead to an increase in the control of the bat, resulting in greater consistency of stroke reproduction.

Stretch (1993c) reported differences in the grip forces when batting on different surfaces and against different paced bowlers, although results for the comparison of artificial and turf pitches and spin and medium-paced bowlers were collected from only two batsmen, both experienced elite cricketers. When playing the drive against medium-paced bowlers on an artificial pitch, smaller forces were generated by the top hand than when playing on a turf pitch. In the drive, forces at impact of 195 N were recorded (FD = 93.6 N) with the peak force of 195 N being reached 0.02 s post-impact (FD = 102 N at 0.04 s pre-impact). The force patterns for the bottom hand before and at impact were similar to those when batting on turf, while a relaxation and re-gripping of the bat during the follow-through was demonstrated when batting on the artificial pitch. The drive played on a turf pitch against a spin bowler demonstrated a peak force of 158 N, which occurred 0.02 s post-impact for the top hand. A similar grip–force pattern was demonstrated for the bottom hand (peak force of 102 N at 0.02 s pre-impact), except that, after impact, a slight re-gripping of the bat occurred as the necessary hand forces were generated to regain control of the bat and to control the inertia of the bat during the follow-through. When playing the forward defensive, the peak forces for the bottom hand (58.4 N) occurred 0.08 s after impact (Stretch, 1993c). These differences may be attributable to the artificial pitch being faster than turf, with a more consistent and predictable bounce and with the ball not spinning or seaming as much as on turf.

When playing the drive against a spin bowler on an artificial surface, the top hand demonstrated a similar, although smaller, grip–force pattern than when batting on turf, with the exception that the peak forces were reached 0.04 s post-impact (FD peak force = 74.3 N at 0.06 s post impact). The grip–force pattern for the bottom hand again showed a similar force pattern, but with smaller forces than those for the top hand, with a relaxation and then re-gripping post-impact to control the bat during the follow-through. In the forward defensive, the bottom hand showed little change in grip forces throughout the stroke, with a force at impact of 30.1 N, reaching a peak force of 34.4 N at 0.06 s post-impact (Stretch, 1993c).

Injuries

In addition to possessing good technical skills, the modern batsman needs to be very fit, to avoid not only the ‘traditional’ direct injuries of being struck by the ball, but also indirect and overuse injuries as a result of repetitive training for a sport that is becoming more explosive in nature. The various studies of injury incidence in cricket, highlighted below, do not always distinguish injuries to batsmen from those to other players.
The risk of injuries to club cricket players has been estimated to be 2.6 per 10,000 man hours played (Weightman and Browne, 1971; Temple, 1982). These figures exclude injuries thought to be trivial, as well as many chronic overuse injuries. The rate of injury to first-class cricketers in Australia has been estimated to be 1 per 30 man-hours played (Payne et al., 1987). Provincial cricketers (71.6%) were reported to be at a greater risk of injury than schoolboy (49.0%) and club cricketers (28.4%; Stretch, 1993b). Deaths from cricket date back to the passing of Frederick Louis, the Prince of Wales and father of George III, who died hours after being struck on the head by a cricket ball (Temple, 1982). Blonstein (1966) suggested that six deaths per year occurred in the UK as a result of playing cricket. From the self-report questionnaire responses of 183 (59%) of 308 cricketers canvassed, Stretch (1993b) found that serious injuries are sustained more frequently during matches by club and provincial cricketers (69.3%) than at practices (26.1%). In schoolboy cricketers, 45.6% of the injuries were sustained both in matches and at practices. In both groups, the balance of the injuries were chronic injuries or injuries that occurred during training.

Although bowling is the major cause of injuries at all standards of the game, batting accounted for 17.1% of the injuries to club and provincial cricketers, with muscle pulls and impact injuries the most common (Stretch, 1993b). In schoolboy cricketers, the batsmen sustained 29.8% of the injuries, of which 17.5% were impact injuries to the head and face. The incidence of injury to the head, neck and face has been reported as 17.5% in schoolboy cricketers, 9% in club and provincial players, 17.5–20% in provincial players (Stretch, 1989) and 25% in club cricketers (Temple, 1982). Most head injuries were a result of being struck by the ball while trying to hook, by the ball deflected off the top-edge of the bat on to the head while playing a horizontal-bat stroke, or as a result of being struck by the ball rearing off the pitch. These injuries were sustained when the batsmen were batting either without a helmet or with a helmet with earpiece side-guards only; they included concussions, a broken nose and cheekbones, and lacerations requiring stitches around the eyes, mouth and chin.

Eye injuries in cricket were first reported at the beginning of the century (Ogilvie, 1900), with later cases of chronic glaucoma secondary to trauma (D’Omain, 1945) and ocular concussion (Littlewood, 1982) having been reported. Four cases of severe eye injuries, including retina detachment and rupture of the globe, were documented in batsmen, accounting for 9.0% of sport-related eye injuries. These resulted from the ball deflecting off the top-edge of the bat while hooking, and striking the eye on the side of the dominant hand (Jones and Tullo, 1986). A survey over 18 months carried out at the Sussex Eye Hospital revealed five minor eye injuries caused by playing cricket, which accounted for 5.4% of all the eye injuries recorded in sports within that period (Gregory, 1986).

Many cricket injuries have been found to be either recurring injuries from the previous season or injuries that recurred later in the season. Twenty percent of the injuries sustained on an international tour were re-aggravated injuries from the previous season (Smith, 1991), while 23.9% of the injuries to club and provincial cricketers were reported to be recurrent injuries and 22.7% of the new injuries sustained were re-aggravated again during that season (Stretch, 1993b). Of the injuries sustained by schoolboy cricketers, 29.8% involved a recurrence of an old injury, while 36.8% of the new injuries sustained occurred again during the same season. Injuries have been reported as occurring fairly regularly throughout the season, with a slight increase during the early and latter part of the season (Stretch, 1989, 1993b). Overuse injuries have been reported to be more common towards the end of the season (Corrigan, 1984), which would appear to be a result of both the concentration of cricket and players not fully recovering from previous injuries.

The upper limb accounted for 24.6% of the injuries in schoolboy cricketers, 25% of injuries in club cricketers (Temple, 1982), 32% in provincial cricketers (Stretch, 1989) and 34% in provincial and club cricketers (Stretch, 1993b). Batting injuries consisted primarily of fractures, dislocations and contusions of the fingers, which were found to be the most vulnerable site for injuries (Corrigan, 1984; Gregory, 1986; Jones and Tullo, 1986; Stretch, 1989, 1993b).

The danger of a fracture, as a result of being struck by the ball while batting, to the distal third of the ulna, rib fractures and soft tissue injuries, especially to the upper leg, abdomen and testicles, have been reported by Corrigan (1984). The case of a splenic rupture, and another of a young player requiring splenectomy for a ruptured spleen after blunt trauma from a cricket ball, were reported by Du Toit and Rademan (1987).

Top- and middle-order batsmen have been found to be more susceptible to impact injuries to the head, phalanges, metacarpals and to lower arm injuries than lower-order batsmen (Stretch, 1989). Payne et al. (1987) reported that bowlers sustained most impact injuries while batting. Lower limb injuries were mainly hamstring, quadriceps and calf muscle pulls as a result of running between the wickets (Weightman and Browne, 1971; Temple, 1982; Payne et al., 1987; Stretch, 1989).

Forward (1988) recorded all the indoor cricket injuries that were reported at the Royal Perth Hospital over a 6-month period. He found that the 64 patients
treated were 19–34 years old (50 males, 14 females). Fielding (72%) and batting (17%) resulted in the major share of these injuries: no injuries were sustained while bowling. The most common injuries were to the fingers and thumb. Fifty percent of the injured players required time off work, with 30% being off work for more than 1 week and 10% being hospitalized.

Coroneo (1985) recommended that ocular protective devices should be worn when playing indoor cricket after reporting four cases of ocular injuries in cricketers. From the many case reports and studies on the incidence of injuries to cricketers, the indications are that the major areas of concern to batsmen are impact injuries to the head, face and fingers. Although cricket injuries have not reached serious proportions, cognisance needs to be taken of these patterns so that the risks of injury can be reduced even further.

**Equipment**

**Bats**

The centre of percussion is important in the design of all sports equipment used to hit balls, including cricket bats. If the bat-to-ball impact occurs through the centre of percussion, then no force is transmitted to the hands. The centre of percussion will alter with the position of the grip on the handle. This sensitivity is reduced if the centre of mass is closer to the centre of percussion; for example, by the build up of the mass of the cricket bat around its centre of percussion (Bartlett, 1997). It is, perhaps, surprising, given the amount of research into the positioning of the 'sweet spot' on tennis rackets, that such little research has been reported on the optimal design of cricket bats. There is little published information on how the position of the centre of percussion is affected by different weights or shapes of bat and little research into other aspects of optimal bat design.

Modern wooden cricket bats have been assessed for their effectiveness as implements to strike the ball by Wood and Dawson (1977). The five bats tested showed distinct differences in hitting effectiveness because of their physical properties. Consistent differences were found between the theoretically obtained centres of percussion. The total impact time between bat and ball was 40–70 ms, with the major shock dissipated in the first 20–30 ms after impact. A weak relationship was found between the weight of the bat and the moments of inertia.

Elliott and Ackland (1982) compared aluminium and wooden cricket bats and found that they had similar dimensions, weight, static balance and resistance to rotational motion. The location of the experimental centres of percussion of the senior-sized aluminium bats was further from the handle than that for the wooden bats, which was similar to the findings of Wood and Dawson (1977). The experimental centres of percussion of the junior-sized wooden and aluminium bats were very similar. Both groups of aluminium bats showed three to four times greater recoil impulses and, on average, produced a greater rebound coefficient than the wooden bats. Wooden bats demonstrated better rebound characteristics than aluminium bats. Elliott and Ackland (1982) contended that more research needs to be done into aluminium bats before they can become a viable replacement for wooden bats; at present, aluminium bats are rarely used in cricket.

**Batting gloves**

Stretch and Tyler (1995) compared the impact characteristics and the efficiency to absorb impact forces of four types of cricket batting gloves using the drop test to simulate four impact speeds: slow-medium, fast-medium, fast and express. In this test, a weighted ball was dropped vertically onto the surface of the batting glove with the vertical forces measured by sensors in a cricket bat handle. The structure and composition of the protective part of the gloves over the index and middle fingers were different in all four makes of gloves. Three of the pairs of gloves (G1, G2 and G3) were composed of two protective components, whereas the fourth (G4) had only one. In the gloves for which there were two protective components, the outer part consisted of sponge-foam-polyurethane that was 10, 10 and 8 mm thick for G1, G2 and G3, respectively. The density of this padding appeared to be less in G3 than in the others. The main difference, however, was that, in addition to the protection offered by this, G3 had additional protection in the form of a 3 mm thick flat plastic reinforcement over the outer part of the padding of the index and middle fingers.

The second protective layer of the gloves varied, with G2 and G4 made up of a similar component to their outer layers, 16 and 10 mm thick, respectively. Gloves G1 and G3 were made up of a layer of tightly compacted padding in each of the fingers. In G1 and G3, a thin sponge covering formed the innermost layer of protection. The only glove with one protective layer, G4, differed from the other three gloves in that this section consisted of four layers. First, it had a thin plastic reinforcement 1 mm thick, with a 2 mm foam covering on the outer side, over each of the fingers. Secondly, in each finger, the middle layer consisted of a 10 mm thick composition similar to the outer and middle layers in G2. Finally, the innermost layer, which was 7 mm thick, was made from a component that appeared to be less dense than the previous layer.
Significant differences between the force absorption characteristics were found at all speeds except slow-medium. At fast-medium, significant differences were found between G1 and G2. At fast speed, G2 and G4 differed significantly, while at express speed, G4 differed significantly from both G2 and G3, and G3 differed significantly from G2. These differences were a result of the differences in the structure and composition of this protective part of the gloves. Manufacturers are, however, in the difficult position of having to balance the impact absorption characteristics of the gloves with the comfort required to wear them for long periods.

At the two fastest impact speeds, the gloves that showed the greatest ability to absorb the impact forces of the ball (G3 and G4) were those with a thin plastic reinforcement placed in the outer part of the padding of the index and middle finger (G3) and separately over each of the fingers (G4). This design feature helped to dissipate the impact forces of the cricket ball over a greater area, thus reducing the impact forces on the fingers. These differences were a result of the structure and composition of the protective part of the batting glove, which differed for all four makes of glove. From the results, it would appear that the batting gloves best able to absorb forces at the fastest impact speeds were those that had a thin plastic reinforcement over an extra padded layer of the fingers, plus the normal padding on the fingers.

**Batting pads**

Hrysomalis (1996) reported how such factors as thickness, construction, temperature and humidity affect the shock absorbency of cricket pads. Several of the pads tested showed inadequate protection to repeated drops on the knee roll, especially at higher temperatures and humidities. A high correlation was reported between peak deceleration and the thickness of both the pad knee roll and shin region.

Stretch et al. (1998b) found a significant difference between the impact kinetics of cricket batting pads at various impact speeds. These differences were considered to be a result of the different structure and composition of the protective part of the pads. Some makes of pads were better able to absorb the impact forces of the ball, giving the batsman greater protection, while others were better able to reduce the rebound distance of the ball after impact. From their findings, it would appear that the batting pads best able to absorb the impact forces of a ball bowled at fast to express speeds are manufactured from polyurethane. The traditional batting pads that are in current use have a greater ability to reduce the rebound distance of the ball after impact with the pads. This reduced ball-pad coefficient of restitution is a result of the structure and composition of the protective parts of the pads, which are less rigid.

These rebound characteristics of pads could be either an advantage or a disadvantage when batting, depending on the match; this is not to suggest that batsmen select their pads according to rebound characteristics rather than for protection, comfort or freedom of movement. In Test cricket, where it is more common for fielders to field close to the batsman, pads with a large post-impact rebound distance of the ball could result in the batsman being caught 'bat-pad' (the ball deflected from the bat onto the pads and then being caught by a fielder). Wearing the more traditional pads would reduce this rebound distance, lessening the risk of dismissal in this manner. The converse could, however, apply in limited-overs cricket matches, where the fielders are normally further from the batsman. A batsman wearing pads with a greater post-impact rebound distance might have an advantage by being able to score runs or leg byes from balls deflecting off the pads.

Manufacturers of batting pads are in the difficult position of having to balance the impact absorption and rebound characteristics of the pads with the comfort required to wear them for long periods. Cricket pad manufacturers, aware that the batting pads behave differently under various impact conditions because of the structure and composition of the protective layers of the pads, need to investigate further the impact properties of the components or combinations of components they use in their batting pads.

**Ball and sightscreen colour**

From the batsman’s point of view, either an orange ball used against a black sightscreen or a white ball against a black sightscreen is better than the traditional red ball against a white sightscreen (Martin-Jenkins, 1988). The reaction time for the former combination was 414 ms, compared with 420 ms for a white ball against a black sightscreen and 456 ms for a red ball against a white sightscreen. More recently, Langley et al. (1999) found that neither ball colour (red or white) nor illuminance (571, 1143 or 1714 lux) affected the slip catching performance of five male first-class cricketers. More research of this kind is required to determine scientifically the effects of such changes to the game on batting performance.

**Psychological factors**

Traditionally, cricket players and administrators have neglected the contribution that the sport psychologist, and current trends in sport psychology, can make in the
mental preparation of batsmen. The emphasis has largely been placed on the technical, physical and tactical components; recently, however, more research has been conducted into mental preparation. Batsmen and coaches are becoming more aware of the role that sport psychology can play in the enhancement of performance (see, for example, Bull et al., 1992), although there is plenty of scope for further, good-quality research into the various psychological aspects of batting.

No differences between anxiety and the performance of skilled and semi-skilled cricket batsmen were found in tests when these batsmen were required to discriminate between various bowling deliveries from a videotape presentation (Morris et al., 1985). When required to respond by selecting the appropriate batting stroke, the skilled batsmen recorded lower state anxiety scores, although no differences in cue discrimination were found between the groups. High specificity in the causes and effects of stress in batting have been reported (Morris et al., 1985); these authors suggested that practice in muscle relaxation might reduce stress in batsmen with relatively high state anxiety. Dippnaar and Potgieter (1986) found no significant relationship for anxiety between or within ability groups in first league batsmen and bowlers. They did, however, find significant differences between and within the groups on measures of attentional and interpersonal style. When looking at the more proficient cricketers in each group, spin bowlers were less impulsive and had more self-control than batsmen. Fast bowlers were found to be more intellectually expressive than seam bowlers, and more positively expressive and influenced to a greater extent by external stimuli than spin bowlers. Jones et al. (1988) assessed the affect of anxiety on psychomotor performance of 12 cricketers, 4 days, 1 day, 1 h and immediately before batting. Their results showed no change in cognitive anxiety across the four test sessions, whereas somatic anxiety increased immediately before batting with a corresponding reduction in self-confidence. Simple and discrimination reaction time did not alter, but the error percentage was greater on the discrimination task immediately before batting, which the authors ascribed to increased somatic anxiety.

Many batsmen have been under the impression that wearing a helmet when facing fast bowling helps to reduce anxiety by reducing the possibility of serious head and facial injuries. Davids and Morgan (1988) found that batsmen showed little change in performance-related anxiety, heart rate and the ability to track and play fast bowling when wearing a helmet with bars, a visorless helmet or no helmet at all. These findings imply that batsmen can now face fast bowlers with confidence in the knowledge that their vision has not been affected by wearing a helmet with bars.

At the end of a programme examining the relationship of mental preparation and performance, club cricketers were able to determine personal objectives with regard to control, commitment and mood analysis (Shilbury, 1989). They were also able to isolate factors such as anxiety, nervousness, lack of motivation and poor concentration by gaining a greater understanding of themselves as cricketers and individuals. Only recently have attempts been made to identify and develop the necessary mental skills required for competition by integrating the psychological with the technical and physical aspects of the game. We would argue that, although some studies – such as the one just discussed – have not distinguished between batsmen and other players, batsmen have the most to gain from research into the effects of mental preparation on their performance.

Conclusions and recommendations

The scientific research into aspects of batting in men’s cricket has included the morphology and physiology of cricket batsmen, motor skills, the biomechanics of the various phases of batting strokes, injuries to batsmen and their association with cricket equipment, and psychological factors in batting. The research is patchy in coverage and many topics merit further investigation. These topics include aspects of fitness specificity, for example weight training based on electromyographic evidence, and psychological coping skills.

A high priority should be given to research into injury mechanisms, rather than simple injury statistics, and the role of cricket equipment design in injury prevention. A second priority is for multi- or inter-disciplinary research, linking the biomechanics of batting to the underlying motor control of the movements and the effect of environmental information. Biomechanical studies of the variability of the batsman’s movements are needed, and these should be related to the compensatory variability proposal of ecological psychology.

Additional areas of research should focus on methods of performance enhancement through vision training and the use of virtual reality. Clearly, there is also a need for scientific research into batting in women’s cricket, which has been inadequately researched to date.

References

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